CHAPTER 13
FIELD PROCEDURES

13-1. General Considerations.

a. Regardless of the number of exploratory borings or other preconstruction investigations, information on the size and continuity of groutable, natural openings in rock below the surface will be relatively meager at the start of grouting operations. The presence of groutable voids can be ascertained before grouting and can be verified by grouting, but the sizes, shapes, and interconnections of the voids will be largely conjectural. The art of grouting consists mainly of being able to satisfactorily treat these relatively unknown subsurface conditions without direct observations. One of the benefits of most grouting programs is exploration. A carefully monitored and analyzed drilling and grouting program can provide significant information about a foundation. It cannot be stressed too strongly, however, that the data gathered must be correlated and analyzed to be of any benefit. The discussions of grouting practices in this manual are intended as a guide, but are not expected to replace experience.

b. Grouting procedures depend on the job, policy, objective, geology, contractor, field personnel, and individual judgment and preference. Procedures subject to variations depending on field technique include drilling, washing, pressure testing, selection and adjustment of mixes, changing grouting pressures, flushing the holes and washing the pump system during grouting, use of delays, intermittent grouting, determining the need for additional grout holes, treatment of surface leaks, and maintaining up-to-date records of drilling, grouting, and monitoring.

c. Local adjustments of the angles, orientation, and spacing of grout holes should be made as necessary. New holes should be required as replacements for holes that are prematurely plugged. When adjustments to contract requirements are made, the designers should participate in the decision. The adjustments may include changing the spacing of primary holes, changing the angles and orientation of grout holes, or increasing or decreasing the grouting program.

d. Regardless of how well conceived and designed the grouting program is, the success of the program depends upon the field techniques used and upon good judgment by field personnel. Grouting techniques may not be subject to contractor quality control and should be directed by the Corps field personnel. For this reason, an experienced geologist should be in charge of the grouting program and he should be provided with an adequate staff.

13-2. Drilling Operation.

a. Since drilling is a vital and costly part of the foundation grouting program a record of all pertinent data should be kept by the inspector during

drilling operations. Entries in chronological order should be made in field books and should include all data of interest that would assist in the identification of the physical characteristics of the formation examined and would account for all time spent in drilling. A sample core hole log sheet is shown in figure 15-5. A form for this purpose should be provided for the inspector to enter data as the work progresses. Identification of material encountered and other pertinent remarks of a geologist assigned to the project should also be included in the log. The following general information should be recorded:

(1) The hole number.

(2) Drilling time schedule.

(3) Names of drillers and inspectors.

(4) Size of hole and inclination.

(5) Stations or coordinates of hole.

(6) Type and identification number of bit used, and make of drilling rig.

(7) Elevations of start and of completion of drilling.

(8) Location and cause of core losses, such as open joints or bedding planes, blocking of bit, grinding of intensely fractured rock, soft material, and gouge.

(9) Results of pressure tests.

(10) Location and nature of filled or open cavities.

(11) Sections of hole cemented, reasons for doing so, quantity of cement used, and water-cement ratio.

(12) Water table data at beginning and end of run and specific zones of water loss and gain.

b. Comments in regard to obtaining and recording data about drill manifestations for respective columns in the log sheet are as follows:

(1) An attempt should be made to trap the return water in a vessel of some kind and measure the amount recovered during one minute. Record meter reading on water supply line over short time intervals to determine rate at which water is pumped through the tool string. The color of the water should be recorded at intervals and at changes throughout the run.

(2) The drilling speed should be recorded as the penetration rate, i.e, the time taken to drill a run.

(3) The action of the drill rig, such as jerky, smooth, rough, or steady, should be recorded showing the limits of such action. Particular attention should be paid to the driller, as he may be drilling at a speed too fast to get a core or he may be drilling at a slow rate and wearing out soft material. The drill pressure should be recorded here.

(4) The driller's log column should show the driller's interpretation of the nature of the formation encountered as drilling progresses. The inspector should obtain the driller's opinion without coaching or any discussion that might influence his statement regarding the matter. If the inspector disagrees with the driller, the reasons for doing so should be stated in the report but nothing should be said to change the views of the driller.

c. Non-Cored Holes: In holes drilled with percussion, plug, or other non-coring bits, much of the data from drilling must be obtained from examination of the drill cuttings and fluid. Valuable information can be gathered by correlating the drill action, color of drill water, and description of the cuttings.

d. It will be desirable to have the inspector turn in a transcript of his records at the end of each shift or hole drilled. The filled out forms and the core boxes will ordinarily be turned over to a geologist to complete the analysis and make up the final log sheet.

13-3. Grouting Operations.

a. Washing Holes.

(1) Washing of grout holes immediately prior to the injection of grout is necessary to a grouting program. The purposes of the washing are to remove all drill cuttings and mud from the grout holes and to flush cuttings, sand, clay, and silt from the fractures in the rock. These materials must be removed to the maximum extent possible so that the grout can be injected and so that windows may not later be eroded in the grout curtain by the removal of silt and clay left in place in rock fractures at the time of the grout injection.

(2) Open hole washing is normally done by inserting a small-diameter wash pipe to the bottom of the hole and injecting a jet of water, sometimes in combination with air, to wash out any material in the hole. This process is mandatory in percussion-drilled holes. There will be instances with rotary-drilled holes where it may be determined that the hole is sufficiently cleaned by washing through the drill rods for several minutes after drilling of the hole is complete. In any event, it is essential to verify that the hole is open to its maximum depth and free of any obstructions just prior to an

injection of grout. This may be done by measuring hole depth with a weighted tape measure. An obstructed hole should be washed again prior to grout injection.

(3) After the open hole washing is completed, it is then necessary to pressure wash the rock formation. The rock formation is washed either through a packer or a sealed connection at the collar of the hole. All adjacent grout holes are opened prior to the pressure washing to serve as exit points for the water injected into the hole being pressure washed. Water and, in rare cases, air under pressure are injected into the hole. The washing should be continued as long as the rate of water taken continues to increase or as long as muddy water vents from adjacent holes or surface leaks. Air injected in short bursts into the water is a method used to create turbulence and enhance the erosive action of the water. Air should only be used with extreme caution, in competent rock. Reversing the direction of washing may also be helpful. Reverse washing will make reconnection to the original hole and washing out of the hole necessary for a few minutes prior to grout injection. It is important to be constantly aware that excessive pressure can damage the foundations and previously placed grout. Water pressure and air pressure should not exceed the allowable grouting pressure during pressure washing.

b. Pressure Testing.

(1) Pressure testing is performed as part of the pressure washing operation. Its purposes are to obtain an indication of the permeability of the foundation, to determine the location of permeable zones, to verify seating of the packer for pressure washing, and to evaluate the effectiveness of the pressure washing. Adjacent holes are uncapped during the test to allow venting of the water. Each grout hole must be pressure tested.

(2) The test should be initiated prior to pressure washing by injecting only water into the hole for a minimum of 10 minutes under a steady pressure. The rate of inflow should be measured each minute. After 10 minutes, and if the test indicates that passages in the formation are being opened by the water, pressure washing should be initiated.

(3) After the pressure washing is completed, the pressure test should again be performed for 10 minutes. Records of the before and after pressure tests should be kept and included in the Foundation Report.

(4) The allowable grouting pressure must not be exceeded during pressure testing. Constant supervision must be maintained before and during the pressure testing and pressure washing operations.

c. The grouting equipment should generally be arranged to provide a continuous circulation of grout throughout the system and to permit accurate pressure control regardless of how small the take might be. Fouling of the equipment and lines should be prevented by periodically flushing the system

with water and by constantly circulating the grout. Pressure relief valves should be used for pressure grouting to reduce the possibility of foundation damage from excessive pressure. If gravity pressures are required, pressure relief should be provided by an open standpipe or injection should be directly into a funnel at the top of the holes, nipple, or standpipe.

d. A common rule of thumb in determining the maximum safe pressures for poor or unknown subsurface conditions is that the pressure in pounds per square inch at any elevation should not exceed the depth of rock in feet, plus one-half the depth of overburden materials over the rock in feet. This rule was derived considering only the weight of materials over the zone being grouted. Other factors affecting the maximum safe grouting pressure include rock strength, orientation of rock discontinuities or fractures, consistency of the grout, tightness of the hole, geology, and hydrologic conditions. Higher pressures can safely be used in many cases. Figure 13-1 is a rough

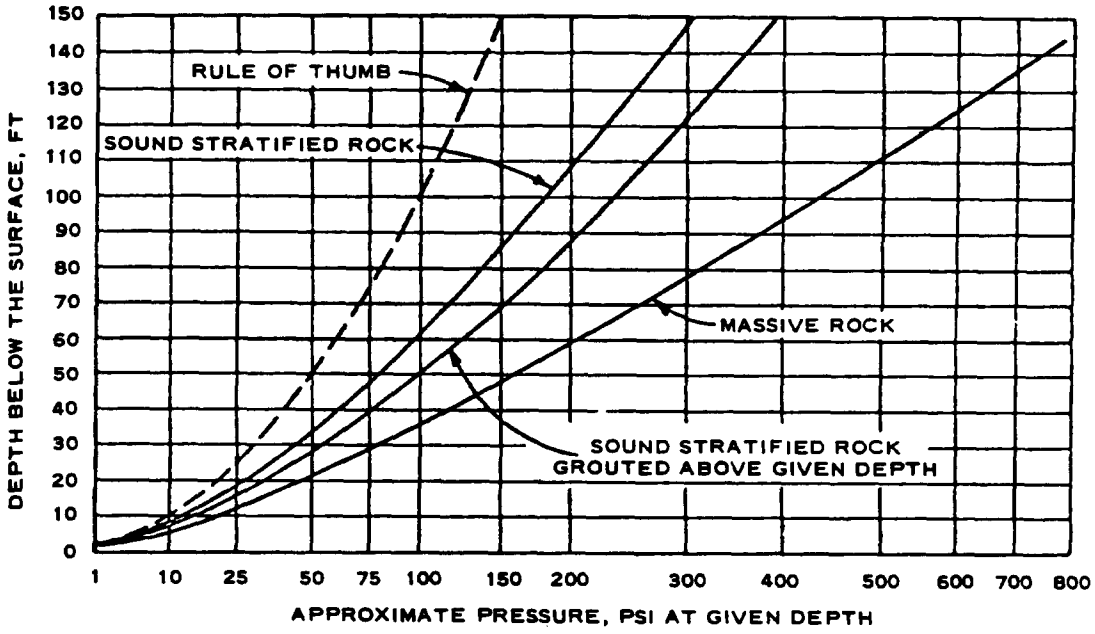

Figure 13-1. Rough guide for grouting pressures

guide for grouting pressures. The pressure exerted by the column of grout above the injection depth must be subtracted from the maximum allowable pressure to determine the maximum gage pressure at the collar of the hole. Examples of pressure computations are included in appendix C.

e. Most foundation grouting is done with grout composed of portland cement, bentonite, and water. The addition of a small percentage (2 to 4 percent) of bentonite produces beneficial results. Settlement is almost eliminated

without a significant reduction in strength or an increase in setting time. The grout is essentially nonshrinking and much superior results are achieved. Fluidizing agents may be added to reduce the viscosity of very thick grouts or for sanded mixes. Water-cement ratios are normally specified by volume of water and dry volume of cement (i.e., 1 sack of cement is considered 1 cubic foot). Figures 5-2 and 13-2 may be used for determining the cement content of various neat cement grout mixes.

f. Thin initial mixes (6:1 or thinner) are usually recommended, especially if the hole is dry or pressure tests indicate slow or small takes. Some formations that are quite pervious refuse 3:1 grout very quickly but will accept 4:1 or 5:1 grout. This justifies beginning with a thin grout even in pervious conditions. If the hole accepts a few batches of the starting mix without pressure buildup, thicker mixes are required; however, if the pressure builds up, grouting may continue with the same mix until refusal. It the rate of injection decreases and the pressure rises, the mix may need to be thinned. Figures 5-3 and 5-4 are charts that may be used in thickening and thinning grout.

g. Mixtures are usually thickened by batching a new mix in the mixer and discharging it into the sump after most of the thinner grout has been injected. If immediate thickening of the mix is required, the hole is shut off temporarily and cement is added to the sump. Mixing is accomplished by agitation of the sump and circulation through the pump and lines.

h. If the hole accepts a few more batches of the new thickened mix without pressure buildup, the next thicker mix is used. The process of thickening the grout continues until the pressure builds up, and then injection is continued. The rate of injection into the hole is slowly cut back when the pressure tends to rise until the hole refuses to take grout at the maximum pressure or meets the specified refusal criteria. As the water-cement ratio decreases, each integer change requires more cement. For example, going from 2:1 to 1:1 requires 67 percent cement. Therefore, mixes of intermediate consistency (e.g., 2.5, 1.5, or 1.25) are used after a consistency of 3.0 or 2.0 is obtained. If extremely thin (8:1 or thinner) grouts are used, a two-integer change is normally used when thickening the grout, i.e., 10:1 to 8:1 to 6:1. When sudden refusal and pressure buildup are experienced, premature plugging may have occurred. If the hole is still taking a small amount of grout, water should be pumped into it to reopen it if possible. After the water has been injected, a thinner grout mix may be required. If the hole is plugged, a new hole may be required. Other causes of sudden refusal include a blocked line, packer, or hole, a collapsed hole, or filled voids.

i. Rising pressures during grouting should be controlled so that they slowly rise in increments until the desired injection pressure is reached. If the injection rate suddenly increases with a drop in pressure when grouting at the maximum safe pressure, lifting should be suspected and appropriate precaution taken.

CUBIC FEET CEMENT CONTAINED IN FOLLOWING MIXES:

CUBIC FEET GROUT	6:1	4:1	3:1	2:1	1.5:1	1:1	.86	.75	.67
0.1					0.1	0.1	0.1	0.1	0.1
0.2			0.1	0.1	0.1	0.1	0.2	0.2	0.2
0.3		0.1	0.1	0.1	0.2	0.2	0.2	0.2	0.3
0.4	0.1	0.1	0.1	0.2	0.2	0.3	0.3	0.3	0.3
0.5	0.1	0.1	0.1	0.2	0.3	0.3	0.4	0.4	0.4
0.6	0.1	0.1	0.2	0.2	0.3	0.4	0.4	0.5	0.5
0.7	0.1	0.2	0.2	0.3	0.4	0.5	0.5	0.6	0.6
0.8	0.1	0.2	0.2	0.3	0.4	0.5	0.6	0.6	0.7
0.9	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.7	0.8
1.0	0.2	0.2	0.3	0.4	0.5	0.7	0.7	0.8	0.9
2.0	0.3	0.4	0.6	0.8	1.0	1.3	1.5	1.6	1.7
3.0	0.5	0.7	0.9	1.2	1.5	2.0	2.2	2.4	2.6
4.0	0.6	0.9	1.1	1.6	2.0	2.7	3.0	3.2	3.4
5.0	0.8	1.1	1.4	2.0	2.5	3.3	3.7	4.0	4.3
6.0	0.9	1.3	1.7	2.4	3.0	4.0	4.4	4.8	5.1
7.0	1.1	1.6	2.0	2.8	3.5	4.7	5.2	5.6	6.0
8.0	1.2	1.8	2.3	3.2	4.0	5.3	5.9	6.4	6.9
9.0	1.4	2.0	2.6	3.6	4.5	6.0	6.6	7.2	7.7
10.0	1.5	2.2	2.9	4.0	5.0	6.7	7.4	8.0	8.6
11.0	1.7	2.4	3.1	4.4	5.5	7.3	8.1	8.8	9.4
12.0	1.9	2.7	3.4	4.8	6.0	8.0	8.8	9.6	10.3
13.0	2.0	2.9	3.7	5.2	6.5	8.7	9.6	10.4	11.1
14.0	2.2	3.1	4.0	5.6	7.0	9.3	10.3	11.2	12.0
15.0	2.3	3.3	4.3	6.0	7.5	10.0	11.1	12.0	12.9
16.0	2.5	3.6	4.6	6.4	8.0	10.7	11.8	12.8	13.7
17.0	2.6	3.8	4.9	6.8	8.5	11.3	12.5	13.6	14.6
18.0	2.8	4.0	5.1	7.2	9.0	12.0	13.3	14.4	15.4
19.0	2.9	4.2	5.4	7.6	9.5	12.7	14.0	15.2	16.3
20.0	3.1	4.4	5.7	8.0	10.0	13.3	14.7	16.0	17.1
21.0	3.2	4.7	6.0	8.4	10.5	14.0	15.5	16.8	18.0
22.0	3.4	4.9	6.3	8.8	11.0	14.7	16.2	17.6	18.9
23.0	3.5	5.1	6.6	9.2	11.5	15.3	16.9	18.4	19.7
24.0	3.7	5.3	6.9	9.6	12.0	16.0	17.7	19.2	20.6
25.0	3.8	5.6	7.1	10.0	12.5	16.7	18.4	20.0	21.4
26.0	4.0	5.8	7.4	10.4	13.0	17.3	19.2	20.8	22.3
27.0	4.2	6.0	7.7	10.8	13.5	18.0	19.9	21.6	23.2

Figure 13-2. Chart for determining cement content of grout mixes

j. It is recommended that the pump system be flushed at intervals with water when thick mixes (i.e., 2.0 or thicker) are used in the grouting procedure. A few cubic feet of water should also be injected into the hole at the same time.

k. A maximum pumping rate should be established for injecting grout to restrain grout travel within reasonable limits and to have better control of the job. Three cubic feet per minute is considered a reasonable maximum pumping rate for most foundation grouting. The rate of grout injection into the hole must be controlled by the Government. The maximum rate is only used when there is no pressure buildup. As the pressure rises, the injection rate is reduced. The rate of injection may also be reduced to restrain grout travel under open-hole conditions. The specifications should clearly indicate that the rate of injection will be controlled by the Contracting Officer's Representative and will vary from the specified refusal criteria to the maximum rate based on pressures and from 0.5 cubic foot per minute to the maximum rate regardless of pressures.

l. When pressures cannot be built up using the thickest mixes allowed, or when it is desirable to prevent grout from spreading too far, delays may be used. They may last from a few minutes to several hours. The amount of grout injected per delay should be controlled to fulfill the intended purpose. If the delays are very long and thick grout is being used, the hole and pump system should be flushed before each delay. The contractor's efforts should also be allowed to be directed elsewhere during the delay. If the delays are short and the contractor is required to stand by, provisions should be made in the contract for payment for standby time. Delays of several hours are required in intermittent grouting for cavity filling. Intermediate, shorter delays during a single injection period may be required to build up the grout cone faster.

m. Upon the completion of grouting a hole, any grout left in the sump should be either wasted or thinned to the starting mix for the next hole. Grout that is not injected within 2 hours after mixing should be wasted, or sooner if the grout shows evidence of stiffening.

n. Split-spaced grout holes may be mandatory according to the contract specifications, or may be required due to grout takes. Split-spaced holes should normally be required on both sides of a hole that takes more grout than the established minimum for the job. Holes that are prematurely plugged should be replaced with new holes. Split-spacing criteria is discussed in para. 13-4c.

o. Drilling and grouting should not be permitted in the same section concurrently. After grouting of a given order of holes is completed and 24 hours has elapsed, the next order of holes may be drilled in the section as required.

p. Surveillance of the area should be made frequently during grouting to check for surface leaks and to collect monitoring data from other holes,

springs, piezometers, wells, and seeps. Records should be kept of any discolorations, changes in flow, or changes in water levels. Leaks are controlled, if necessary, by dikes or calking with materials such as oakum, wood wedges, or burlap. If the leaks are serious, an accelerator may be added to the ponded grout within a diked area and a delay may be used to allow the grout to set. It the leak cannot be stopped, grouting may be continued at reduced pressure with a thicker mix. During grouting or after grouting is completed in each reach, exploratory coreholes should be drilled and pressure tested to check the adequacy of the grouting. These borings may indicate that conditions in all or parts of the formation already grouted will require additional grouting. In such event, the equipment must be returned and additional holes should be drilled and grouted.

q. For winter grouting, all grout should be maintained at temperatures above 50°F until injected. The temperatures of mixing water should range from 50° to 100°F when added to the grout mixer. Storage of grouting materials should be at temperatures above freezing. In addition, when grouting surface rock, the surface temperature should be no colder than 40°F before and during injection and for a period of 5 days thereafter. Insulation, heated enclosures, and water heaters are frequently necessary.

r. In extremely hot weather, grout and grouting materials should be protected from direct sunlight. It is desirable to maintain the grout at temperatures below 90°F. The higher temperatures not only increase water demand and, consequently, shrinkage but also accelerate the setting time of the grout, which decreases the working time.

s. Geologic sections and profiles should be kept up to date with drilling, testing, and grouting data, and records should be made of monitoring data to evaluate the ongoing grouting program. This information should also be included in the foundation report for future reference.

t. Evaluation of grouting effectiveness must be constant and continuous during the program. It should be a joint effort between engineering and construction personnel. If problems develop, reaction should be expeditious. Flexibility must be maintained for making changes and improvements as the program progresses. Design changes of other project features are sometimes made based on knowledge of foundation conditions gained during grouting.

13-4. Completion of Grouting.

a. Grouting may be continued to absolute refusal at the maximum grouting pressure, although this is not usually done. There are two methods that are most frequently used to determine when grouting is complete. One specifies that grouting shall continue until the hole takes no grout at three-fourths of the maximum grouting pressure. The other requires that grouting continue until the hole takes grout at the rate of 1 cubic foot or less in 10 minutes measured over at least a 5-minute period. This is often modified according to

the mix and/or pressure used. The second specification is more readily correlated with pressure test results than the first.

b. If there is doubt about the completeness of treatment in any zone or area, a check hole or holes should be drilled. Such holes can be drilled to recover core for examination, or they may be drilled for study by the borehole camera or television camera. However, a quicker and less expensive check can be made by drilling and pressure testing another grout hole. If tight when pressure tested with water, the rock is satisfactorily grouted; if the hole takes water, additional grouting is indicated.

c. The process of split-spacing should continue as long as there is significant reduction in take with each new series of split-spaced holes, or until takes are not considered to be significant for the particular project.